



AERONAUTICS
WITH YOU WHEN YOU FLY

A NASA Approach to Safety Considerations for Electric Propulsion Aircraft Testbeds

NASA

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NASA Aeronautics

NASA Aeronautics Vision for Aviation in the 21st Century



6 Strategic Thrusts



Safe, Efficient Growth
in Global Operations



Innovation in Commercial
Supersonic Aircraft



Ultra-Efficient
Commercial Vehicles



Transition to
Low-Carbon Propulsion



Real-Time System-Wide
Safety Assurance



Assured Autonomy for
Aviation Transformation

U.S. leadership for a new era of flight

Strategic Thrusts 3 & 4

Hybrid Electric Propulsion Research Themes



Strategic Thrust 3: Ultra Efficient Commercial Vehicles



2015

2025

2035

Evolutionary gains for carbon neutral growth by 2020

Revolutionary improvements to fleet to achieve 2005 levels

Transformational capabilities for 50% reduction of 2005 Levels



Evolutionary



Revolutionary



Transformational

Strategic Thrust 4: Transition to Low Carbon Propulsion



2015

2025

2035

Low-carbon fuels for conventional engines

Introduction of Alternative Propulsion Systems

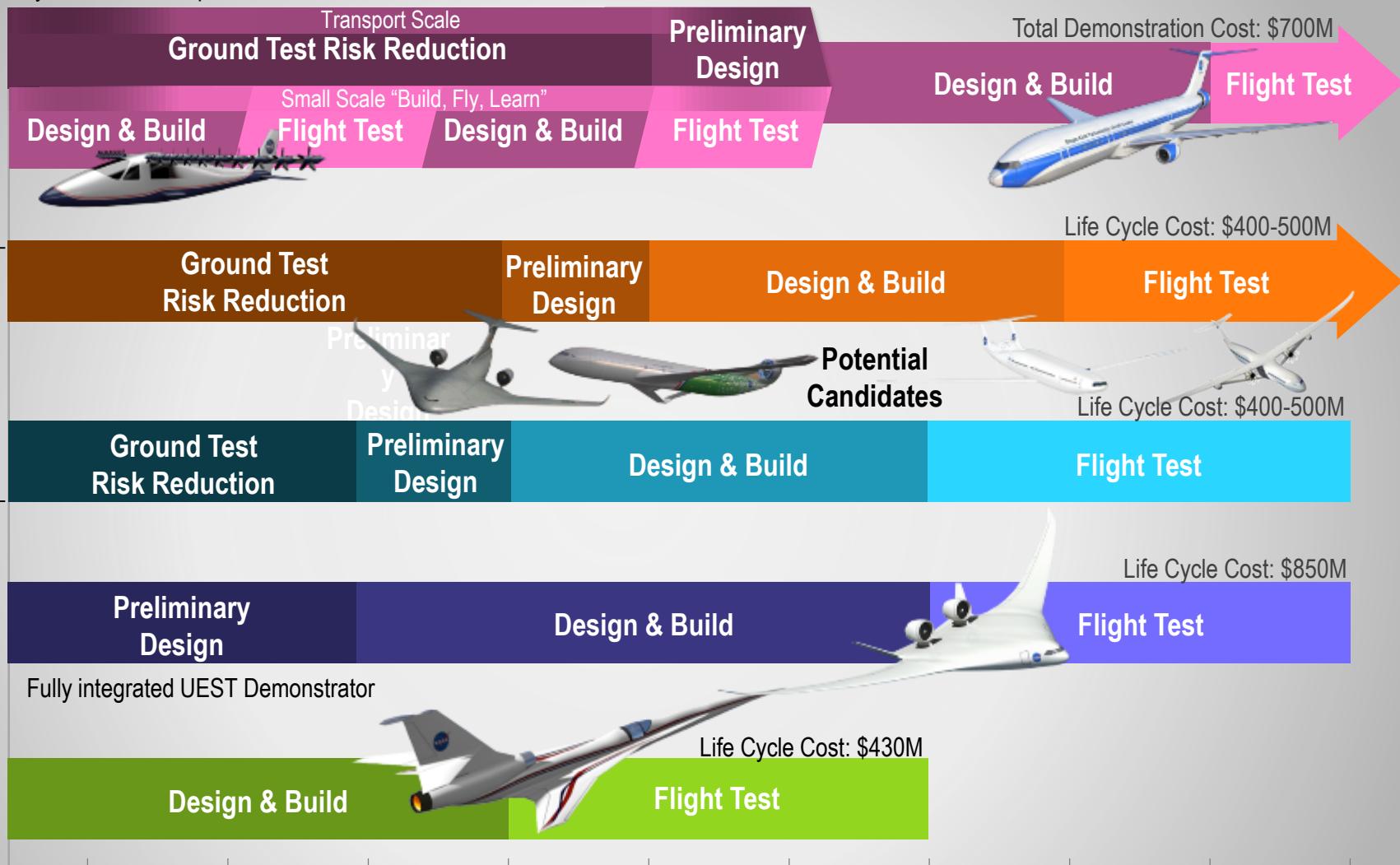
Alternative Propulsion Systems to Aircraft of All Sizes

- **Integrated Technology Concepts (Vehicle / Synergy)**
- **Power and Propulsion Architectures**
- **HEP Components / Enablers**
- **Modeling, Simulation, and Test Capability**

Electric & Hybrid-Electric Flight Demonstration Plan



Hybrid Electric Propulsion Demonstrators



FY17

FY18

FY19

FY20

FY21

FY22

FY23

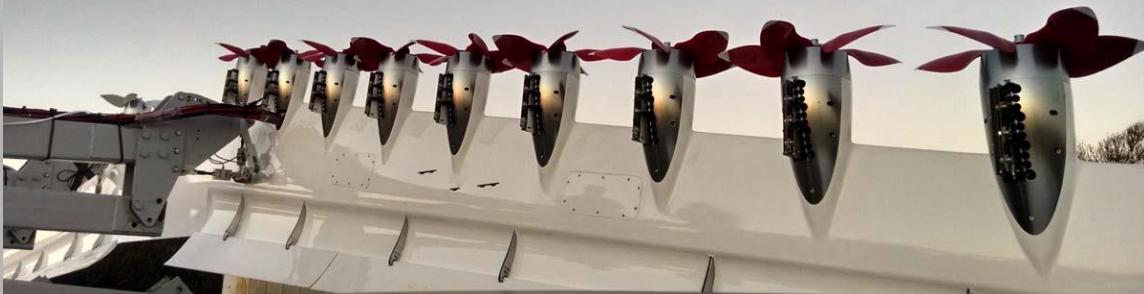
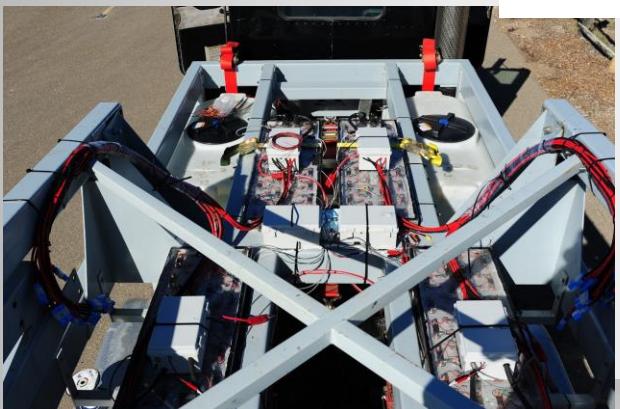
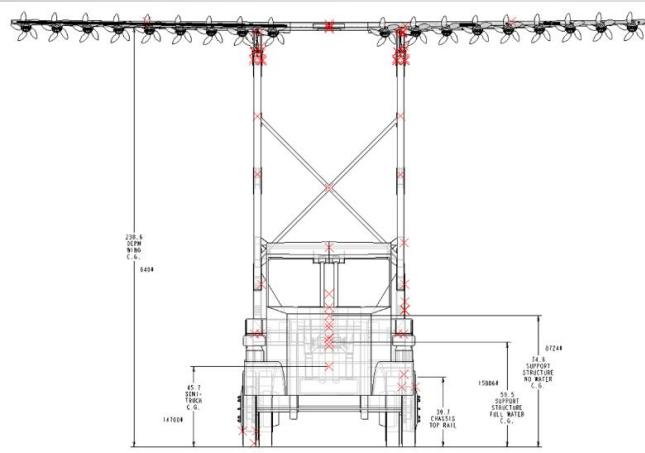
FY24

FY25

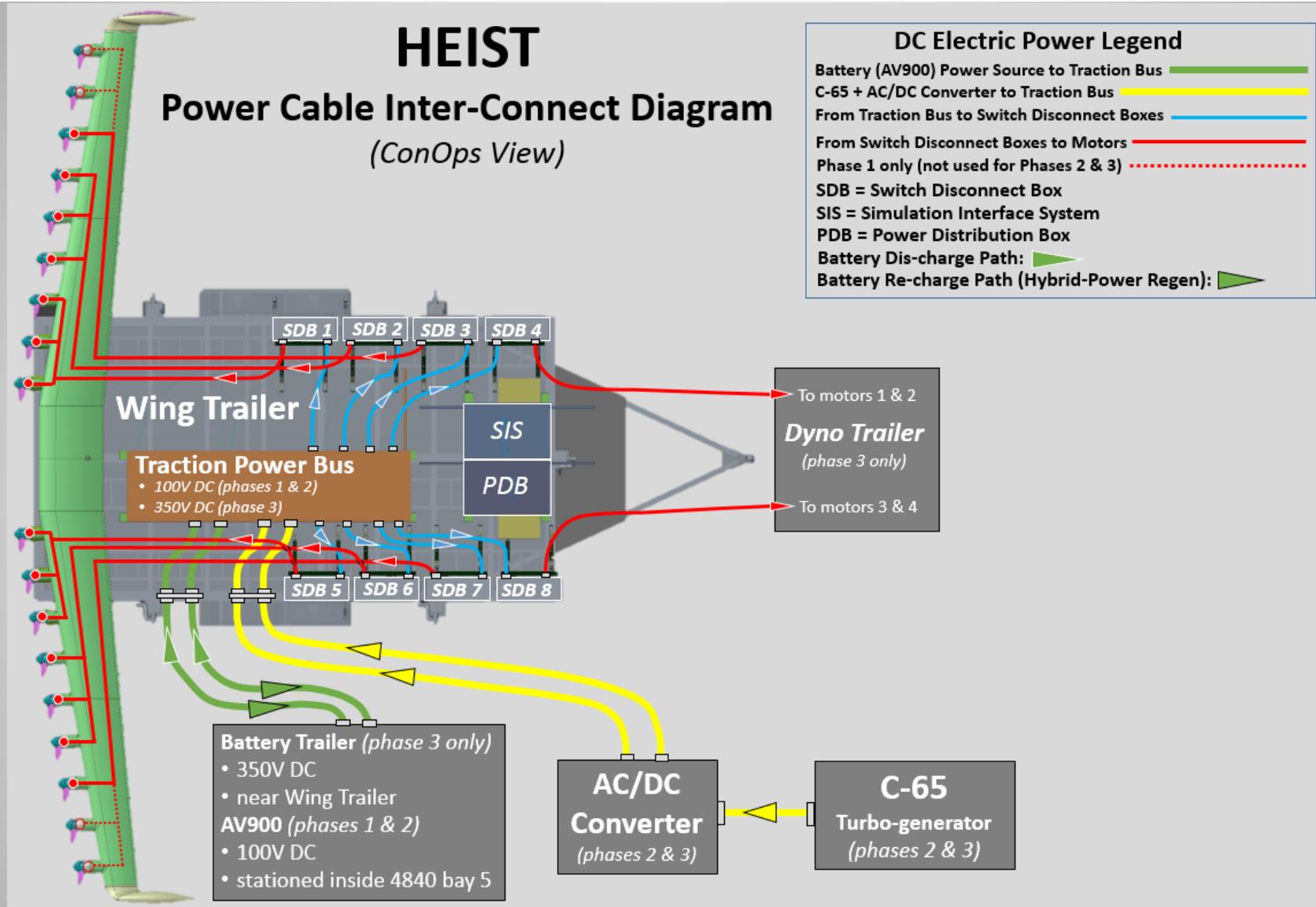
FY26

The LEAPTech Truck Experiment

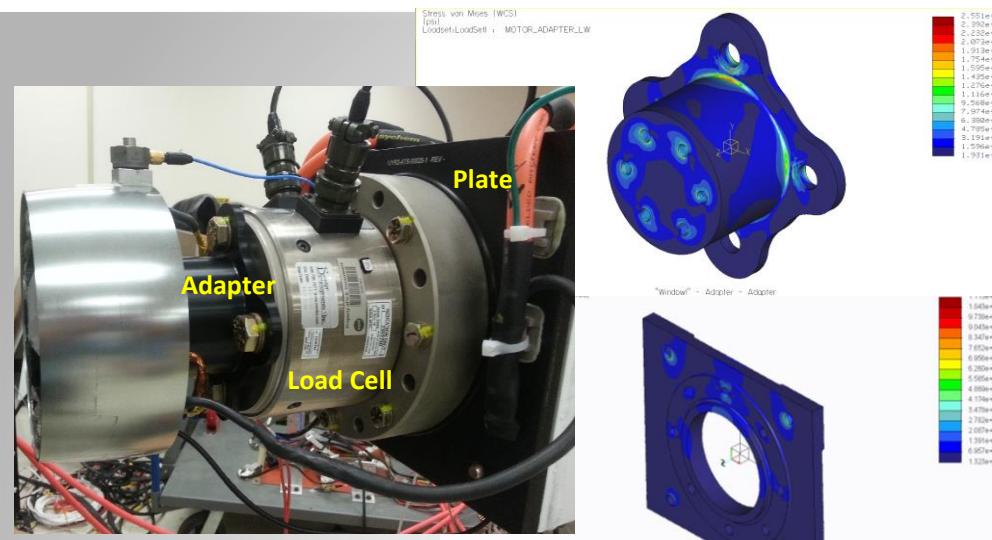
1st Experiment of HEIST



Hybrid-Electric Integrated Systems Testbed (HEIST)



Airvolt – Fully Instrumented, Single-Propulsor Test Stand



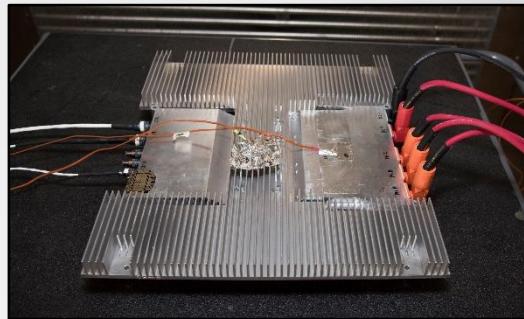
X-57 Maxwell (SCEPTOR)



JSC Test Unit With Interstitial Barrier
and Heat Spreader (Design Template)



X-57 Battery Module ($\frac{1}{4}$ Pack)
before Short Circuit Test

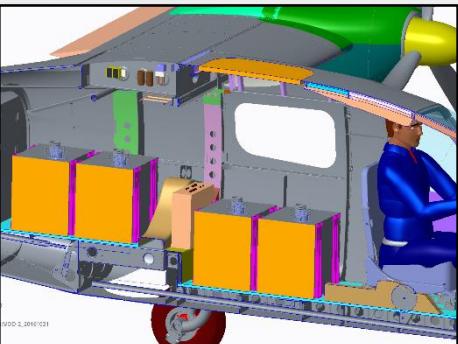


Cruise Motor Inverter
Environmental
Testing at NASA

Prototype Cruise Motor



X-57 Thermal Runaway Unit
(2 Trays; $\frac{1}{2}$ Module)



One Battery Pack
(4 Module, $\frac{1}{2}$ Ship Set)



NASA Armstrong Hazard Assessment Matrices



	Injury severity classifications				
	A: Frequent	B: Probable	C: Occasional	D: Remote	E: Improbable
I: Catastrophic					
II: Critical					
III: Moderate					
IV: Negligible					

	Asset/mission severity classifications				
	A: Frequent	B: Probable	C: Occasional	D: Remote	E: Improbable
I: Catastrophic					
II: Critical					
III: Moderate					
IV: Negligible					

	Requires Center Director approval and may require approval by a higher authority. These hazards are defined as “Accepted Risks.”
	Risk acceptance requires Center Director approval. These hazards are defined as “Accepted Risks.”
	Risk acceptance requires Project Manager approval.

Example of a Distributed Electric Propulsion Hazard



X-57 Maxwell HR-3 traction bus failure										
Causes					Effects					Mitigations
A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	
A. Electrical short	B. Wiring defect	C. Design error	D. Circuit protection component failure	E. Installation error	F. External/environmental abuse (thermal/mechanical)	G. Grounding isolation fault	H. Inadequate grounding	I. Operational / procedural error	J. Lightning strike	* Loss of essential avionics power * Total loss of aircraft power * Motor failure * Propeller governor failure * Fire * Damage or loss of aircraft * Damage to ground assets * Injury or death to personnel
AFRC hazard action matrices										
Probability					Severity					1 Design avionics bus for single fault tolerance (A,B,C,D,E) 2 Ground test (CST) (A,B,C,D,E,F,G,I) 3 Grounding checks (G,H) 4 Design with margin (de-rate power system) (C,D,F) 5 Quality control process (B,E,I) 6 Peer review of design (C) 7 VFR operations only (J) 8 Perform visual inspection of system components (A,B,D,E,F) 9 Adhere to X-57 operational placards and procedures (E,F,H,I,J)
A	B	C	D	E	A	B	C	D	E	
Cat I	☒	☒	☒	☒	☒	☒	☒	☒	☒	
Cat II	☒	☒	☒	☒	☒	☒	☒	☒	☒	
Cat III	☒	☒	☒	☒	☒	☒	☒	☒	☒	
Cat IV	☒	☒	☒	☒	☒	☒	☒	☒	☒	
Human					Asset / Mission					

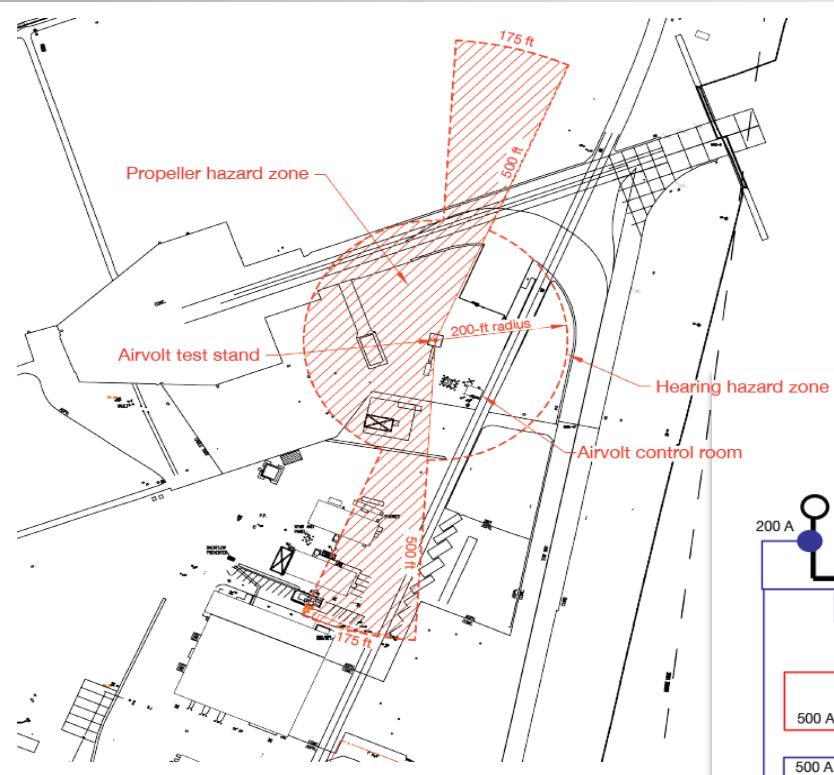
Electric & Hybrid-Electric Testbed-Specific Hazards



Project hazard summary	Severity/probability classification	
	Human	Asset
X-57 Maxwell		
HR-1 Aircraft traction battery fire	I D	I D
HR-2 Structural failure of wing	I D	I D
HR-3 Traction bus failure	I E	I E
HR-5 Aircraft damage due to exposure to excessive environmental conditions during ground operations	N/A	III D
HR-7 Wing control surface system failure	I D	I D
HR-9 Inadequate stability control	I D	I D
HR-11 Failure of motor mounts	I E	I E
HR-12 Whirl flutter	I D	I D
HR-13 Symmetric loss of cruise propeller thrust (partial/total)	II E	II E
HR-14 Avionics bus failure	III E	II E
HR-15 Cruise propeller performance degradation and/or separation	I E	I E
HR-17 Battery modules separate from attach points	I E	I E
HR-18 Abrupt asymmetric thrust	I D	I D
HR-19 Electromagnetic interference in flight	N/A	IV D
HR-20 Landing gear structural failure	II D	I D
HR-21 Failure of propulsor system	I E	I E
HR-22 Restricted and/or obstructed crew egress	I E	N/A
HR-23 Cockpit air contamination	I E	I E
HR-24 Inadvertent cruise motor propeller rotation	I E	III E
HR-25 Equipment pallet separates from attach points	I E	III E
HR-26 Personnel exposed to high voltage/current	I E	N/A
HR-27 High lift propeller damage and/or separation	Analysis in work	
HR-28 Classic flutter	I E	N/A

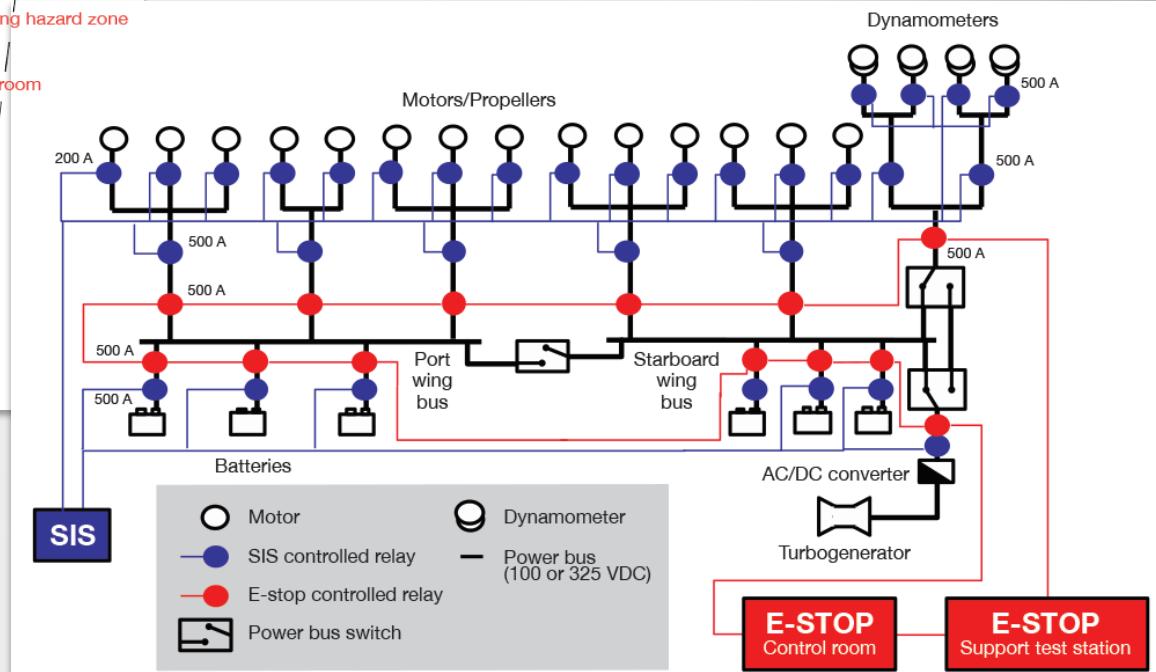
Project hazard summary	Severity/probability Classification	
	Human	Asset
HEIST		
HR-1 Propeller failure	I E	III C
HR-2 Traction battery fire	II E	III D
HR-3 Inadvertent system activation	I E	III E
HR-4 Electrical discharge / shock / arc flash	I E	III E
HR-5 HEIST ground asset collision	I E	II E
HR-6 JM-1 motor failure	I E	IV B
HR-7 Electrical fire	II E	III D
HR-8 Damage to HEIST assets due to environmental factors	N/A	III E
HR-9 Test article support structure failure	I E	III E
HR-10 Excessive noise exposure	II E	N/A
HR-12 Dynamometer system failure	I E	III C
HR-15 Software operation outside of intended parameters	N/A	III C
HR-16 Electromagnetic interference	N/A	IV D
HR-17 Loss of hardware communication link	N/A	IV D
Airvolt		
HR-1: Lithium polymer battery fire	II E	IV E
HR-2: Airvolt test stand structural failure	I E	III E
HR-3: Electrical fire	III D	II E
HR-4: Electrical discharge/shock	I E	III E
HR-5: Propeller / motor failure	I E	IV E
HR-6: Test personnel exposed to excessive noise during system operation	II E	N/A

Distributed Electric Propulsion Hazard Mitigation Examples



Propeller and audio decibel-level threshold
keep out zone

Manual hardware-only Emergency-Stop (E-Stop)
relay network

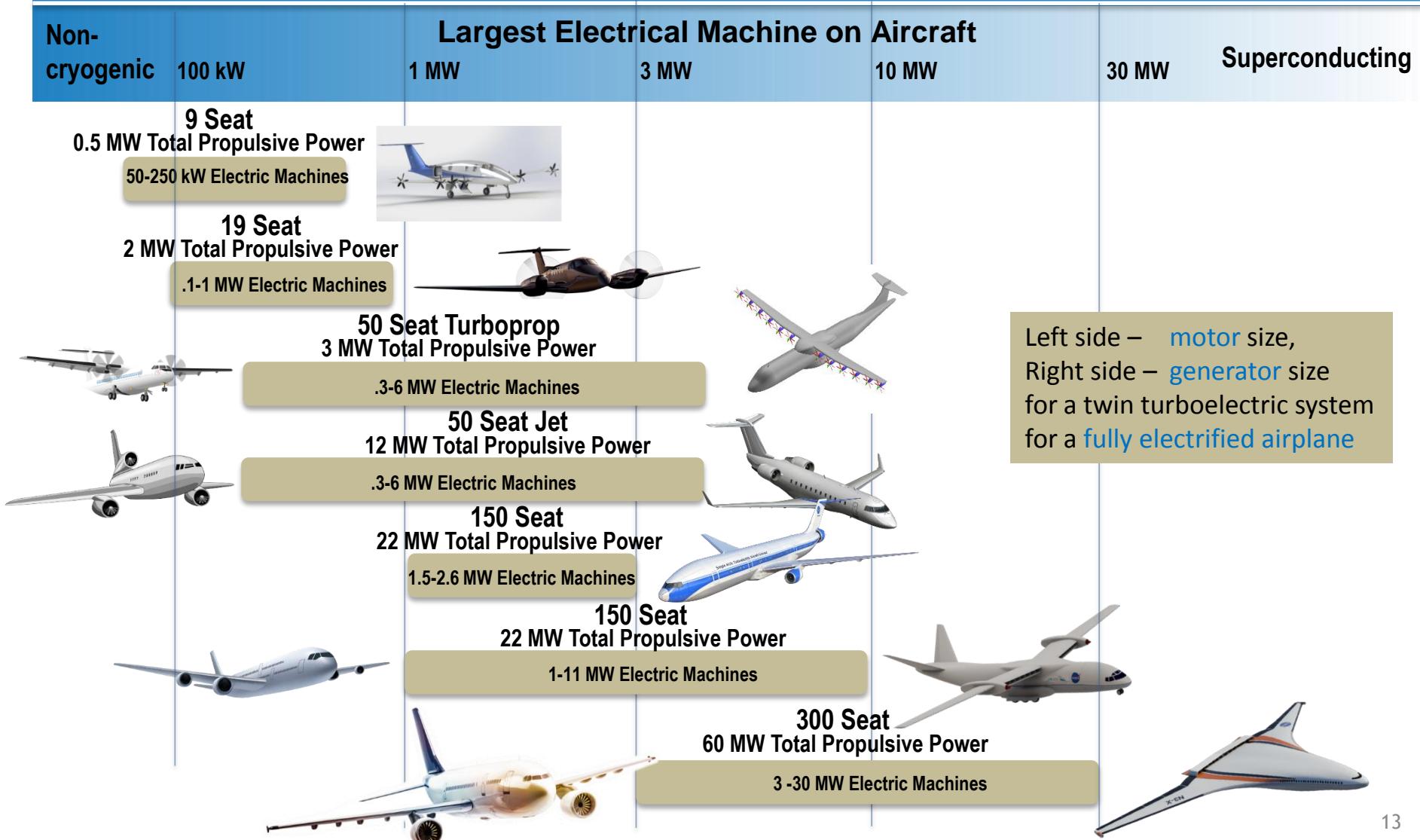


Where do we go from here?



2015

2035



Backup Slides

